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Objective: To examine birth outcomes in military women and men with potential exposure to documented open-air burn pits before and during pregnancy. **Methods:** Electronic data from the Department of Defense Birth and Infant Health Registry and the Defense Manpower Data Center were used to examine the prevalence of birth defects and preterm birth among infants of active-duty women and men who were deployed within a 3-mile radius of a documented open-air burn pit before or during pregnancy. **Results:** In general, burn pit exposure at various times in relation to pregnancy and for differing durations was not consistently associated with an increase in birth defects or preterm birth in infants of active-duty military personnel. **Conclusions:** These analyses offer reassurance to service members that burn pit exposure is not consistently associated with these select adverse infant health outcomes.

Service members and their health care providers have raised concerns about potential health risks from exposure to smoke created by open burning of solid waste at military bases in Iraq and Afghanistan. Among these concerns is the possibility that burn pit exposure may affect the health of their future-born children. In recent years, environmental reproductive health has emerged as an important field of study, focusing on exposures to environmental contaminants (particularly those that occur during critical periods in development such as before conception and during pregnancy) and their potential effects on all aspects of reproductive health. [1] Studies suggest that maternal exposure to air pollutants during pregnancy may be associated with a spectrum of adverse birth outcomes including an increased risk of birth defects (particularly cardiac anomalies), low birth weight, intrauterine growth retardation, and preterm delivery (PTD).[2–7] In addition, exposure to air pollutants in men has been associated with reduced sperm quality, and there is evidence that paternal exposures to environmental contaminants before conception may adversely affect birth outcomes as well.[8–12]

Air sampling commissioned by the Department of Defense (DoD) at documented burn pit sites detected the following pollutants with potentially harmful health effects: respirable and fine particulate matter, lead, mercury, polycyclic aromatic hydrocarbons, volatile organic compounds, toxic organic halogenated dioxins and furans (dioxins), and irritant gases.[13] Airborne particulate matter has been identified as the component of air pollution likely to be responsible for the link between maternal exposure during pregnancy and altered fetal growth and gestational duration (ie, low birth weight, intrauterine growth retardation, and PTD).[6,14,15] In addition, there is suggestive evidence that paternal exposure to dioxins, a class of highly toxic and widely dispersed compounds that are the unintentional byproducts of processes such as combustion and incineration, is associated with neural tube defects.[11] A recent congressional hearing on the use of burn pits in Iraq and Afghanistan included testimony suggesting that the slow, low-temperature characteristics of this type of burning emit an array of chemicals with the potential to harm the respiratory, cardiovascular, immune, and reproductive health of service members.[16]

This study leverages a large existing electronic birth registry, the DoD Birth and Infant Health Registry (the Registry), to examine the impact of possible burn pit exposure on the prevalence of birth defects and preterm birth among infants of active-duty military women and men.

METHODS

The Registry was established in 1998 and uses comprehensive health care data to define live births and infant health outcomes based on *International Classification of Diseases*, 9th Revision, Clinical Modification (ICD-9-CM) medical diagnostic coding, including birth defects and preterm birth, through the first year of life among infants born to DoD beneficiaries.[17] Live-born infants of active-duty military women and men born between January 1, 2004, and December 31, 2007, were identified using the Registry. Birth defects were defined by nationally accepted ICD-9-CM diagnostic codes as detailed by the National Birth Defects Prevention Network and included ICD-9-CM codes in the range of 740.x to 760.x.[18] Registry data are routinely validated by review of a sample of birth defect cases with criteria established by the Metropolitan Atlanta Congenital Defects Program.[17,19] Preterm birth was assessed using an infant's estimated gestational age (EGA) at birth, defined by ICD-9-CM codes, specifically by code 765.2x, with the maximum end of each range assigned as the infant's EGA at birth. For code 765.29, EGA of 40 weeks was assumed. If a 765.2x code was not assigned, then 765.0x and 765.1x codes were used to assign EGA at birth, where the shorter EGA was assumed to be correct if both codes were present. Infants assigned 765.0x were assumed to have reached EGA of 28 weeks, and infants assigned 765.1x were assumed to have reached EGA of 36 weeks. The maximum end of each gestational age range for preterm infants was applied in recognition that the distribution of actual gestational ages is skewed toward the overall mean (40 weeks). Applying the maximum end of the gestational age range

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also allowed the largest possible time window for maternal exposure in each pregnancy to be included. If more than one 765.2x code existed for a single infant, the most recent code assigned was used, and the shorter EGA was used if multiple codes appeared on the same day. Babies born with an EGA of 36 weeks or less were considered preterm. If an electronic record lacked any of the above-mentioned codes, full term was assumed. Parental demographic and deployment information was obtained from the Defense Manpower Data Center.

The primary analyses compared infants born to military women and men after deployment to a region within a 3-mile radius of a documented open-air burn pit at Joint Base, Balad, Iraq; Camp Taji, Iraq; or Contingency Operating Base Speicher, Iraq, with infants born to military personnel after deployment in support of the operations in Iraq and Afghanistan, but to a region outside a 3-mile radius of a documented burn pit. Secondary analyses investigated deployment to regions within a 2- or 5-mile radius of the three burn pits.

Infants born to active-duty military women (maternal model, $N = 13{,}129$) were considered exposed if their mother deployed to a burn pit region any time before or during pregnancy, with the onset of pregnancy defined by the first day of the last menstrual period (LMP), $n = 1171$. The date of the LMP was estimated as date of birth minus EGA at birth. Infants born to spouses of active-duty military men (paternal model, $N = 88{,}074$) were considered exposed if their father was deployed to a burn pit region before the infant's estimated date of conception (EDC), $n = 6703$, with EDC estimated as the LMP plus 14 days. Additional analyses included variables for the temporality (or proximity in time) of the parents' exposure to the onset of pregnancy (maternal model) or EDC (paternal model), cumulative days of exposure to a burn pit region before the infant's date of birth (maternal model) or EDC (paternal model), and last exposed deployment, defined as the parent's duty location (ie, Joint Base Balad, Camp Taji, or Contingency Operating Base Speicher) in the exposed time period closest to the onset of pregnancy (maternal model) or EDC (paternal model). Analyses including the latter variable, last exposed deployment, were included to determine if there were differences between the three documented burn pit sites studied with respect to the prevalence of birth defects, preterm birth, or both in the infants of military personnel serving there.

In the absence of individual-level exposure data, it is possible that those deployed personnel in the referent population (ie, those deployed in support of the operations in Iraq and Afghanistan, but to a region outside a 3-mile radius of a documented burn pit) may have had some burn pit exposure. Although the burn pits at Joint Base Balad, Camp Taji, and Contingency Operating Base Speicher are among the largest, there are other burn pits located throughout the theater of operations. In an attempt to obtain a comparison group with less possibility of misclassification of burn pit exposure status, an additional population, infants born to Camp Arifjan deployers ($n = 118$ for active-duty women and $n = 415$ for active-duty men) and defined as personnel deployed to Camp Arifjan for a period of time equal to or longer than the cumulative days deployed elsewhere in support of the operations in Iraq and Afghanistan, was extracted from the original referent population and used as a referent population in primary model supplemental analyses. Camp Arifjan, which is located in Kuwait and therefore has similar meteorological conditions to the documented burn pit sites, is notable because waste is collected and transported out of the area for disposal.

Analyses included descriptive investigations of parental demographic and occupational characteristics stratified by deployment status. Analyses were restricted to Army and Air Force personnel because of the low number of Navy and Marine Corps personnel located within a 3-mile radius of the documented open-air burn pits in the sample. Preliminary univariate analyses, including chi-square tests and odds ratios (ORs), were performed to assess the significance of associations between the outcomes of interest (birth defects and preterm birth) and burn pit exposure. An exploratory model analysis was completed to assess regression diagnostics, significant associations, and collinearity while simultaneously adjusting for all other variables in the model.

Multivariable logistic regression models were used to estimate the adjusted ORs and 95% confidence intervals of birth defects and preterm birth among infants with the exposure of concern. All models were adjusted for multiple birth, infant sex, maternal age, and sponsor demographics, including race/ethnicity, branch of military service, rank, military occupation, and duty status. In addition, maternal models were adjusted for marital status. All statistical analyses were performed using SAS software, version 9.2 (SAS Institute, Inc., Cary, NC).

RESULTS

Descriptive characteristics of the service members and their infants included in this study are displayed in Table 1. Maternal age (ie, age of the deployer in the maternal model and the deployer's spouse in the paternal model) was lower (<35 years) among deployers with potential burn pit exposure (exposed deployment) compared with deployers without burn pit exposure (other deployment). Service women and men with an exposed deployment were more likely to be Army, enlisted personnel on active duty and less likely to be in a combat occupation. In addition, deployed women with burn pit exposure were more likely to be of Hispanic or other/unknown race, compared with white, and unmarried. Deployed men with burn pit exposure were more likely to be in a health care occupation and their spouses were more likely to have a multiple birth.

In the primary maternal model, infants born to active-duty military women deployed within a 3-mile radius of a burn pit before or during pregnancy were not at increased odds of being diagnosed with a birth defect in the first year of life or being born preterm (Table 2). Likewise, neither timing of exposure in relation to onset of pregnancy nor cumulative exposure time was significantly associated with an increase in birth defects or preterm birth among infants of this group of women (Tables 3 and 4). Finally, analysis of last exposed deployment revealed no significant differences between sites with respect to either adverse birth outcome (data not shown). Results of additional analyses using both 2- and 5-mile radii for defining exposure status were consistent (data not shown). Of note, in each of the three models (2-, 3-, and 5-mile) in which timing of exposure was assessed, the group of infants born to women deployed to a burn pit region during pregnancy had consistently elevated ORs for birth defects, although none ever attained statistical significance.

Infants of active-duty military women were more likely to be diagnosed with a birth defect if they were male or if their mother was in the Air Force compared with the Army. They were less likely to be diagnosed with a birth defect if their mother was of an unknown or other race compared with those of white race.[20] Infants were more likely to be born preterm if they were part of a multiple birth and if their mother was 35 years of age or older or black, and they were less likely to be born preterm if their active-duty mother was an officer (Table 2).

In the primary paternal model, deployment within a 3-mile radius of a burn pit was not significantly associated with an increase in birth defects or preterm birth when controlling for all other variables in the model (Table 5). However, when timing of exposure in relation to EDC was analyzed, a significantly increased risk of birth defects was found among infants born to men who were exposed more than 280 days before EDC, although there were no significant associations with PTD in this model (Table 6). Analyses of cumulative exposure time showed no significant association with either adverse outcome (Table 7). Likewise, analysis of last exposed deployment revealed no significant differences between sites with respect to either adverse birth outcome (data not shown). Results of analyses using a 5-mile radius for defining exposure status were consistent, with the exception that in the 5-mile model, a

TABLE 1. Descriptive Characteristics of Service Members and Their Infants by Burn Pit Exposure Status, 2004–2007

	Women				Men			
	Other Deployment*		Exposed Deployment†		Other Deployment*		Exposed Deployment†	
	N	%	*N*	%	*N*	%	*N*	%
Total	11,958		1,171		81,371		6,703	
Any birth defect								
No	11,575	96.8	1,129	96.4	78,324	96.3	6,456	96.3
Yes	383	3.2	42	3.6	3,047	3.7	247	3.7
Birth status								
Full term	11,079	92.6	1,076	91.9	75,437	92.7	6,191	92.4
Preterm	879	7.4	95	8.1	5,934	7.3	512	7.6
Multiple status								
Singleton	11,820	98.8	1,156	98.7	80,362	98.8	6,591	98.3
Multiple	138	1.2	15	1.3	1,009	1.2	112	**1.7‡**
Infant gender								
Female	5,790	48.4	579	49.4	39,636	48.7	3,301	49.2
Male	6,168	51.6	592	50.6	41,735	51.3	3,402	50.8
Maternal age, yr								
<35	11,043	92.3	1,118	**95.5‡**	74,251	91.2	6,201	**92.5‡**
≥35	915	7.7	53	4.5	7,120	8.8	502	7.5
Race								
White	5,609	46.9	500	42.7	57,656	70.9	4,696	70.1
Black	3,869	32.4	388	33.1	10,878	13.4	948	14.1
Hispanic	1,446	12.1	158	**13.5‡**	8,113	10.0	654	9.8
Other/unknown	1,034	8.6	125	**10.7‡**	4,724	5.8	405	6.0
Marital status								
Married	8,330	69.7	768	65.6	81,371	100.0	6,703	100.0
Unmarried	3,628	30.3	403	**34.4‡**	-	0.0	-	0.0
Branch of service								
Army	6,587	55.1	820	**70.0‡**	54,392	66.8	5,009	**74.7‡**
Air force	5,371	44.9	351	30.0	26,979	33.2	1,694	25.3
Rank								
Enlisted	10,417	87.1	1,049	**89.6‡**	65,226	80.2	5,597	**83.5‡**
Officer	1,541	12.9	122	10.4	16,145	19.8	1,106	16.5
Occupation								
All other	9,686	81.0	972	83.0	50,710	62.3	4,474	66.7
Health care	1,420	11.9	162	13.8	3,659	4.5	404	**6.0‡**
Combat	852	7.1	37	**3.2§**	27,002	33.2	1,825	**27.2§**
Duty status								
Regular	10,676	89.3	1,093	**93.3‡**	69,703	85.7	6,185	**92.3‡**
Reserve/other	1,282	10.7	78	6.7	11,668	14.3	518	7.7

*Deployment in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a burn pit.
†Deployment in Iraq within a 3-mile radius of a documented burn pit.
‡Women and men with exposed deployment more likely to be younger (<35 years), Army, enlisted, regular duty status; women additionally more likely to be Hispanic or of another/unknown race, and unmarried; men additionally more likely to have a multiple birth, and to be in a health care occupation.
§Women and men with exposed deployment less likely to be employed in a combat occupation.
Numbers in **bold** indicate significance at $P < .05$.

significantly decreased risk of birth defects was found among infants of men with burn pit exposure 34 to 125 days before EDC (OR, 0.75; 95% confidence interval, 0.56 to 0.996, data not shown). Results of analyses using a 2-mile radius for defining exposure status revealed no significant associations with either adverse outcome, even when variables for timing of exposure in relation to EDC, cumulative exposure time, or last exposed deployment were analyzed (data not shown).

For the primary paternal model, infants born to spouses of active-duty military men were more likely to be diagnosed with a birth defect if they were part of a multiple birth, male sex, or if their mother was 35 years of age or older. They were less likely to be diagnosed with a birth defect if their active-duty father was black or Hispanic or if his military specialty was in the area of health care. These infants were more likely to be born preterm if they were part of a multiple birth, male sex, their mother was 35 years of age or

TABLE 2. Adjusted Odds of Birth Defects and Preterm Birth Among Infants of Female Deployers in Relation to Burn Pit Exposure, 2004—2007

	All Infants	Infants With Birth Defects					Infants Born Preterm				
Effect	***N***	***n***	**%**	**OR***	**95% CI**	***P***	***n***	**%**	**OR***	**95% CI**	***P***
Deployment						0.33					0.48
Other deployment†	11,958	383	3.2	1.00§			879	7.4	1.00§		
Exposed deployment‡	1,171	42	3.6	1.18	0.85–1.63		95	8.1	1.09	0.86–1.37	
Multiple status						0.16					<0.01
Singleton	12,976	417	3.2	1.00§			877	6.8	1.00§		
Multiple	153	8	5.2	1.69	0.82–3.47		97	63.4	24.31	**17.29–34.20**	
Infant gender						<0.01					0.31
Female	6,369	174	2.7	1.00§			461	7.2	1.00§		
Male	6,760	251	3.7	**1.37**	**1.12–1.66**		513	7.6	1.07	0.94–1.23	
Maternal age, yr						0.87					0.02
<35	12,161	392	3.2	1.00§			882	7.3	1.00§		
≥35	968	33	3.4	0.97	0.67–1.41		92	9.5	**1.35**	**1.06–1.73**	
Race/ethnicity						0.02					<0.01
White	6,109	205	3.4	1.00§			412	6.7	1.00§		
Black	4,257	148	3.5	1.10	0.88–1.38		394	9.3	**1.34**	**1.15–1.57**	
Hispanic	1,604	52	3.2	1.04	0.76–1.42		97	6.0	0.92	0.72–1.16	
Other/Unknown	1,159	20	1.7	**0.52**	**0.33–0.83**		71	6.1	0.90	0.69–1.18	
Marital status						0.26					0.23
Married	9,098	289	3.2	1.00§			641	7.0	1.00§		
Unmarried	4,031	136	3.4	1.13	0.91–1.41		333	8.3	1.10	0.94–1.27	
Branch of service						<0.01					0.08
Army	7,407	221	3.0	1.00§			599	8.1	1.00§		
Air force	5,722	204	3.6	**1.32**	**1.07–1.62**		375	6.6	0.88	0.76–1.02	
Rank						0.11					0.04
Enlisted	11,466	361	3.1	1.00§			872	7.6	1.00§		
Officer	1,663	64	3.8	1.30	0.95–1.78		102	6.1	**0.77**	**0.60–0.99**	
Occupation						0.18					0.19
All other	10,658	351	3.3	1.00§			820	7.7	1.00§		
Health care	1,582	52	3.3	0.96	0.71–1.30		107	6.8	0.80	0.58–1.10	
Combat	889	22	2.5	0.65	0.42–1.02		47	5.3	0.86	0.69–1.08	
Duty status						0.28					0.63
Regular	11,769	372	3.2	1.00§			877	7.5	1.00§		
Reserve/other	1,360	53	3.9	1.19	0.87–1.64		97	7.1	1.06	0.84–1.35	

CI, confidence interval; OR, odds ratio.

*Model is adjusted for multiple birth, infant sex, maternal age, maternal race/ethnicity, maternal branch of military service, maternal rank, maternal military occupation, maternal duty status, and marital status.

†Deployment in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a burn pit.

‡Deployment in Iraq within a 3-mile radius of a documented burn pit.

§Indicates reference category.

Numbers in **bold** indicate significance at $P < 0.05$.

older, their father was black, or he was in a reserve/other duty status compared with regular active duty. They were less likely to be born preterm if their father was Hispanic, in the Air Force, or an officer (Table 5).

Results of supplemental analyses using infants of those deployed to Camp Arifjan as a referent population were as follows: There were no differences in the prevalence of birth defects or preterm birth when infants born to military personnel with an exposed deployment (ie, deployed to one of the three burn pit sites studied) or those remaining in the original referent population (ie, infants born to personnel who were deployed in support of operations in Iraq and Afghanistan but to a region outside a 3-mile radius of a burn pit) were compared with infants born to those deployed to Camp Arifjan (data not shown).

DISCUSSION

The increasing number of women on active duty has heightened concern about the potential for military-unique exposures to impact the reproductive health of service members, especially because it has been well established that harmful exposures during the early prenatal period, often before the pregnancy is recognized, are associated with adverse birth outcomes.[21] To prevent exposure to potentially harmful substances in the operational environment from negatively impacting birth outcomes in female personnel, military policy precludes deployment during pregnancy. Some pregnancies, such as those that are recognized after deployment, are exposed nonetheless. Results of a previous study are reassuring in that infants born to women who were inadvertently deployed during early pregnancy were not at increased risk for being born preterm or being

TABLE 3. Adjusted Odds of Birth Defects and Preterm Birth Among Infants of Female Deployers: Timing of Burn Pit Exposure in Relation to Onset of Pregnancy: 3-Mile Model, 2004—2007

	All Infants	Infants With Birth Defects					Infants Born Preterm				
Effect	***N***	***n***	**%**	**OR***	**95% CI**	***P***	***n***	**%**	**OR***	**95% CI**	***P***
Deployment proximity						0.55					0.72
Other deployed†	11,958	383	3.2	1.00‡			879	7.4	1.00‡		
≥291 days§	266	8	3.0	0.96	0.47–1.97		15	5.6	0.84	0.50–1.43	
108–290 days	268	8	3.0	0.96	0.47–1.96		23	8.6	1.15	0.73–1.81	
1–107 days	264	9	3.4	1.12	0.57–2.20		23	8.7	1.27	0.82–1.98	
In pregnancy¶	373	17	4.6	1.55	0.94–2.57		34	9.1	1.08	0.74–1.58	

CI, confidence interval; OR, odds ratio.
*Model is adjusted for multiple birth, infant sex, maternal age, maternal race/ethnicity, maternal branch of military service, maternal rank, maternal military occupation, maternal duty status, and marital status.
†Deployment in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a burn pit.
‡Indicates reference category.
§Days from the end of the most recent deployment within a 3-mile radius of a burn pit, to the onset of pregnancy as defined by the first day of the last menstrual period, grouped by tertile.
¶Deployed during pregnancy.

TABLE 4. Adjusted Odds of Birth Defects and Preterm Birth Among Infants of Female Deployers: Cumulative Days of Burn Pit Exposure Before Infant's Date of Birth, 2004—2007

	All Infants	Infants With Birth Defects					Infants Born Preterm				
Effect	***N***	***n***	**%**	**OR***	**95% CI**	***P***	***n***	**%**	**OR***	**95% CI**	***P***
Cumulative deployment						0.64					0.52
Other deployed†	11,958	383	3.2	1.00‡			879	7.4	1.00‡		
<78 days§	292	10	3.4	1.17	0.61–2.23		24	8.2	1.02	0.65–1.59	
78–132 days	290	14	4.8	1.52	0.88–2.63		22	7.6	1.15	0.74–1.79	
133–193 days	294	10	3.4	1.08	0.57–2.05		19	6.5	0.83	0.51–1.36	
≥194 days	295	8	2.7	0.92	0.45–1.89		30	10.2	1.35	0.91–2.02	

CI, confidence interval; OR, odds ratio.
*Model is adjusted for multiple birth, infant sex, maternal age, maternal race/ethnicity, maternal branch of military service, maternal rank, maternal military occupation, maternal duty status, and marital status.
†Deployment in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a burn pit.
‡Indicates reference category.
§Cumulative days of deployment within a 3-mile radius of a burn pit prior to infant's date of birth, grouped by quartile.

diagnosed with a major birth defect or malignancy during the first year of life when compared with infants born to women who were deployed at other times or never deployed.[22]

In the present study, possible exposure to smoke from open-air burn pits, occurring at various times in relation to pregnancy and for differing durations, was not significantly associated with an increase in birth defects or preterm birth in infants of active-duty women. However, in each of the three maternal models (2-, 3-, and 5-mile) in which timing of exposure was assessed, the group of infants born to women deployed during pregnancy had consistently elevated ORs for birth defects, although none ever attained statistical significance. Evidence in the literature is convincing that exposure to air pollution during pregnancy impacts fetal growth and length of gestation.[6,7,14,23,24] It has been proposed that this effect is mediated by particulate air pollutants that, via several different cardiovascular mechanisms, interfere with the transport of oxygen and nutrients across the placenta, although the exact biologic mechanism remains to be elucidated.[15] Epidemiologic studies of air pollution and birth defects are accumulating, but results are equivocal at best.[2–5,25] Although it is not possible to rule out an association between burn pit exposure and the prevalence of birth defects in this small subgroup of women, other more likely explanations exist. First, because military policy precludes deployment during pregnancy, it is likely these pregnancies were recognized late, and late recognition of pregnancy has been associated with an increased risk of birth defects.[26] In addition, because of the late recognition of pregnancy, it is possible that women exposed during pregnancy were more likely to smoke, drink alcohol, or both during pregnancy compared with women exposed at other times, and we were unable to adjust for such lifestyle behaviors that are widely known to impact birth outcomes. Finally, it must be noted that the number of women with burn pit exposure during pregnancy was small, and the observed birth defects were among those most commonly seen in the Registry rather than a clustering of the same birth defect of a more rare nature, making an association with burn pit exposure less plausible.

Historically, paternal exposures to environmental/occupational contaminants have been studied in terms of their impact on fertility, but there is some evidence that they may play a role in adverse birth outcomes as well. For example, studies have linked paternal exposures to pesticides, herbicides, and ionizing radiation with adverse birth outcomes including spontaneous abortions, birth defects, and malignancies in childhood.[12,27] More recently, exposure to air pollution has been associated with altered sperm quality including DNA damage, suggesting that a paternally

TABLE 5. Adjusted Odds of Birth Defects and Preterm Birth Among Infants of Male Deployers in Relation to Burn Pit Exposure, 2004—2007

	All Infants	Infants With Birth Defects					Infants Born Preterm				
Effect	***N***	***n***	**%**	**OR***	**95% CI**	***P***	***n***	**%**	**OR***	**95% CI**	***P***
Deployment						0.77					0.79
Other deployment†	81,371	3,047	3.7	1.00§			5,934	7.3	1.00§		
Exposed deployment‡	6,703	247	3.7	0.98	0.86–1.12		512	7.6	1.01	0.92–1.12	
Multiple status						<0.01					<0.01
Singleton	86,953	3,222	3.7	1.00§			5,847	6.7	1.00§		
Multiple	1,121	72	6.4	**1.78**	**1.40–2.27**		599	53.4	**15.96**	**14.14–18.02**	
Infant gender						<0.01					<0.01
Female	42,937	1,337	3.1	1.00§			2,924	6.8	1.00§		
Male	45,137	1,957	4.3	**1.41**	**1.31–1.52**		3,522	7.8	**1.17**	**1.11–1.23**	
Maternal age, yr						<0.01					<0.01
<35	80,452	2,946	3.7	1.00§			5,750	7.1	1.00§		
≥35	7,622	348	4.6	1.29	**1.15–1.45**		696	9.1	1.33	**1.22–1.45**	
Race/ethnicity						<0.01					<0.01
White	62,352	2,415	3.9	1.00§			4,501	7.2	1.00§		
Black	11,826	403	3.4	0.86	**0.77–0.95**		1,061	9.0	1.19	**1.11–1.28**	
Hispanic	8,767	288	3.3	0.84	**0.74–0.95**		546	6.2	0.84	**0.76–0.92**	
Other/unknown	5,129	188	3.7	0.94	0.81–1.10		338	6.6	0.91	0.81–1.02	
Branch of service						0.08					<0.01
Army	59,401	2,252	3.8	1.00§			4,537	7.6	1.00§		
Air force	28,673	1,042	3.6	0.93	0.87–1.01		1,909	6.7	0.88	**0.83–0.93**	
Rank						0.10					<0.01
Enlisted	70,823	2,666	3.8	1.00§			5,351	7.6	1.00§		
Officer	17,251	628	3.6	0.92	0.83–1.02		1,095	6.3	**0.74**	**0.68–0.80**	
Occupation						0.04					0.36
All other	55,184	2,090	3.8	1.00§			4,041	7.3	1.00§		
Health care	4,063	124	3.1	**0.79**	0.66–0.95		324	8.0	1.03	0.98–1.09	
Combat	28,827	1,080	3.7	**0.98**	0.91–1.06		2,081	7.2	1.07	0.95–1.21	
Duty status						0.98					0.02
Regular	75,888	2,841	3.7	1.00§			5,553	7.3	1.00§		
Reserve/other	12,186	453	3.7	1.00	0.90–1.11		893	7.3	**1.10**	**1.02–1.20**	

CI, confidence interval; OR, odds ratio.

*Model is adjusted for multiple birth, infant sex, maternal age, paternal race/ethnicity, paternal branch of military service, paternal rank, paternal military occupation, and paternal duty status.

†Deployment in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a burn pit.

‡Deployment in Iraq within a 3-mile radius of a documented burn pit.

§Indicates reference category.

Numbers in **bold** indicate significance at $P < 0.05$.

mediated impact of air pollution on birth outcome is possible.[8–10,28] Overall, burn pit exposure was not significantly associated with an increase in birth defects or preterm birth among infants of active duty men. Nevertheless, when timing of exposure in relation to EDC was analyzed, a significantly increased risk of birth defects was found among infants born to men who were exposed more than 280 days before EDC. The length of the spermatogenic cycle in humans is 74 days, representing the time it takes for spermatogonial stem cells to be transformed into differentiated motile spermatozoa capable of fertilization. This period of intense cellular transformation, involving mitosis, meiosis, differentiation, and maturation, is believed to be highly susceptible to environmental insults.[12] It seems likely that if burn pit exposure was associated with the increased prevalence of birth defects observed among infants of men with exposure more than 280 days before EDC, a consistently increased prevalence would have been observed in the quartiles closer to EDC as well, since 280 days represents nearly four complete spermatogenic cycles. In fact, there was no apparent linear or graded increasing risk for birth defects among infants of men with burn pit exposure closer to EDC. In addition, although the finding of an increased prevalence of birth defects among infants of men with exposure more than 280 days before EDC was consistent in the 5-mile model, it was not consistent in the 2-mile model, in which the men potentially had the greatest exposure (presuming those closest to the burn pit had the most exposure), providing additional evidence that this finding may be spurious. Finally, there was no clustering of the birth defects observed in this subgroup of infants. Rather, they represented a distribution generally seen in the Registry, making an association with burn pit exposure less likely as well. Confounding variables that we were unable to evaluate include maternal exposures, both before and after conception, which are generally considered more concerning than paternal exposures, and other environmental/occupational paternal exposures that may have occurred closer to EDC (ie, subsequent to the exposed deployment).

TABLE 6. Adjusted Odds of Birth Defects and Preterm Birth Among Infants of Male Deployers: Timing of Burn Pit Exposure in Relation to Estimated Date of Conception, 2004—2007

	All Infants	Infants With Birth Defects					Infants Born Preterm				
Effect	***N***	***n***	**%**	**OR***	**95% CI**	***P***	***n***	**%**	**OR***	**95% CI**	***P***
Deployment proximity						0.03					0.26
Other deployed†	81,371	3,047	3.7	1.00‡			5,934	7.3	1.00‡		
≥281 days§	1,685	82	4.9	**1.33**	**1.06–1.67**		139	8.3	1.11	0.92–1.33	
126–280 days	1,675	59	3.5	0.94	0.72–1.22		138	8.2	1.14	0.95–1.37	
34–125 days	1,675	48	2.9	0.75	0.56–1.01		117	7.0	0.91	0.75–1.11	
<34 days	1,668	58	3.5	0.91	0.70–1.18		118	7.1	0.90	0.74–1.10	

CI, confidence interval; OR, odds ratio.
*Model is adjusted for multiple birth, infant sex, maternal age, paternal race/ethnicity, paternal branch of military service, paternal rank, paternal military occupation, and paternal duty status.
†Deployment in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a burn pit.
‡Indicates reference category.
§Days from the end of the most recent deployment within a 3-mile radius of a burn pit, to the estimated date of conception, grouped by quartile.
Numbers in **bold** indicate significance at $P < 0.05$.

TABLE 7. Adjusted Odds of Birth Defects and Preterm Birth Among Infants of Male Deployers: Cumulative Days of Burn Pit Exposure Before Estimated Date of Conception, 2004—2007

	All Infants	Infants With Birth Defects					Infants Born Preterm				
Effect	***N***	***n***	**%**	**OR***	**95% CI**	***P***	***n***	**%**	**OR***	**95% CI**	***P***
Cumulative deployment						0.29					0.86
Other deployed†	81,371	3,047	3.7	1.00‡			5,934	7.29	1.00‡		
<72 days§	1,658	54	3.3	0.85	0.64–1.11		128	7.72	0.98	0.81–1.18	
72–130 days	1,660	63	3.8	1.02	0.79–1.32		127	7.65	1.04	0.86–1.25	
131–200 days	1,707	75	4.4	1.20	0.95–1.51		119	6.97	0.95	0.79–1.16	
≥201 days	1,678	55	3.3	0.86	0.66–1.13		138	8.22	1.09	0.91–1.30	

CI, confidence interval; OR, odds ratio.
*Model is adjusted for multiple birth, infant sex, maternal age, paternal race/ethnicity, paternal branch of military service, paternal rank, paternal military occupation, and paternal duty status.
†Deployment in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a burn pit.
‡Indicates reference category.
§Cumulative days of deployment, within a 3-mile radius of a burn pit, before the estimated date of conception, grouped by quartile.

There are several limitations to this study. Parental demographic and deployment information was obtained from Defense Manpower Data Center, the only source for such information, and we were unable to verify the accuracy of these data or estimate misclassification. Furthermore, despite ongoing attempts to improve individual-level exposure data, there remains the potential for misclassification of exposure status. This is especially important when small numbers are being analyzed and multiple comparisons are being conducted, which may allow these findings to potentially be due to chance alone. Within the exposed group, it is likely there were different levels of exposure that we were unable to differentiate. In addition, this study was not able to incorporate important information such as the direction and density of the smoke plume during burning operations, and types of material burned, into exposure status. Difficulties with obtaining accurate individual-level exposure data aside, linking exposures to environmental contaminants with adverse birth outcomes presents a great challenge. Air sampling has determined that burn pit smoke, like most environmental exposures, is a dynamic combination of several different factors (eg, particulate matter, irritant gases, dioxins, and various other components), depending on the materials burned, which interact with each other and with the unique genetic make-up of the individual as well as with any other relevant exposures that may be present, to result in a potential outcome. Isolating the role of the environmental exposure in this outcome can be extremely complex. The limitations that result when intermittent environmental data, such as air sampling, are used to determine health risk have been described.[29] As previously mentioned, it was not possible to adjust for late recognition of pregnancy; use of tobacco, alcohol, drugs, and other substances during pregnancy; or the effects of other potentially confounding occupational and environmental exposures. It is possible, therefore, that consideration of these factors may have identified a subset of individuals, (eg, smokers or those with accumulated air pollution exposure due to permanent residence in an urban setting) who are more susceptible to the effect of burn pit exposure. Likewise, it was not possible to adjust for stress during pregnancy, which has been shown to potentially affect birth outcomes such as preterm birth and birth defects.[30–32] Because the Registry captures data about live-born infants, the investigation of pregnancy terminations, miscarriages, and stillbirths, all of which are important outcomes that may be associated with exposure to environmental pollutants, was not feasible. In addition, there may be some infants in the Registry who, for various reasons such as parental separation from service or a change in health insurance coverage, have less than a full year of health

care information in the database. These analyses relied on the use of electronic databases for both parental and infant information, and both EDC and LMP were estimated using date of birth and EGA. Despite several levels of validation, misclassification bias may have occurred when identifying the timing of pregnancy or deployment, introducing some degree of error. Finally, data analyzed were from documented burn pits in three camps only, and it was not possible to assess burn pit exposure over the entire theater of operations.

Despite these limitations, there are several important strengths of this study. The Registry is the most comprehensive registry of birth defects in infants born to military personnel, capturing health care data through the first year of life. It contains nearly all diagnosed birth defects because approximately 95% are diagnosed before the end of infancy.[10] Linked with electronic data from the Defense Manpower Data Center, which provides objective measures of demographic variables and deployment dates of all military personnel, this study provides an important look at the prevalence of birth defects and preterm birth in infants of military personnel with burn pit exposure. Using these databases allowed for an appropriate referent population to be defined as infants born to military personnel deployed in support of the operations in Iraq and Afghanistan outside a 3-mile radius of a documented open-air burn pit. This group is thought to be a more optimal referent population than infants of nondeployers or infants of all active-duty personnel because of the medical clearance process required for deployment. Known as the "deployer effect," deploying personnel are potentially healthier than their nondeploying counterparts. Use of infants of those deployed to Camp Arifjan as an alternate referent population was included to strengthen analyses by avoiding the possibility of misclassification of burn pit exposure status. The usefulness of this referent population may be limited, however, by its small size and potential confounding by stress. Located in Kuwait, Camp Arifjan may be a less stressful deployment location than the burn pit sites, which are located in Iraq.

Service members, news outlets, and members of Congress have expressed concern that exposure to smoke emitted from open burning of waste at bases in Iraq and Afghanistan is causing adverse health effects. In principle, exposure to environmental pollutants such as smoke from open burn pits could cause birth defects via a preconception mutagenic effect (maternal and paternal) or a postconception teratogenic effect (maternal), although the precise cause of most birth defects remains unclear.[33,34] Although birth defects are on the severe end of the spectrum of adverse pregnancy outcomes potentially associated with environmental exposures, equally concerning is the more common outcome of PTD.[33,35] Along with low birth weight and intrauterine growth retardation, PTD is considered a general indicator of altered fetal growth, and is of concern not only for its associated increased neonatal morbidity and mortality but also for its associated long-term consequences, which include neurodevelopmental and behavioral impairments in childhood and adolescence.[36] These analyses may offer reassurance; in general, potential burn pit exposure at various times in relation to pregnancy and for differing durations was not significantly associated with an increase in birth defects or preterm birth among infants born to active-duty women and men. Future analyses should focus on improving the quality of individual-level exposure data by integrating information about smoke plume direction and density into exposure status, as well as incorporating information about the types of materials burned, which in turn determines the chemicals emitted, to better assess the potential impact of open-air burn pit smoke exposure on reproductive and infant health outcomes.

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14. ABSTRACT

Background
Studies suggest that maternal exposure to air pollutants during pregnancy may be associated with a spectrum of adverse birth outcomes including an increased risk of birth defects (particularly cardiac anomalies), low birth weight (LBW), intrauterine growth retardation (IUGR), and preterm delivery (PTD). Additionally, exposure to air pollutants in men has been associated with reduced sperm quality, and there is evidence that paternal preconception exposures to environmental contaminants may adversely affect birth outcomes as well.
Methods: Electronic data from the Department of Defense Birth and Infant Health Registry and the Defense Manpower Data Center were used to examine the prevalence of birth defects and preterm birth among infants of active-duty women and men who were deployed within a 3-mile radius of a documented open-air burn pit before or during pregnancy.
Results: In general, burn pit exposure at various times in relation to pregnancy and for differing durations was not consistently associated with an increase in birth defects or preterm birth in infants of active-duty military personnel.
Conclusions: These analyses offer reassurance to service members that burn pit exposure is not consistently associated with these select adverse infant health outcomes.

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